U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-295 321

Determination of Radium Removal Efficiencies in Water Treatment Processes

(U.S.) Office of Radiation Programs, Washington, DC

Dec 76

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. ORP/TAD-76-5	2.
3. RECIPIENT'S ACCESSION NO. PB295321	
4. TITLE AND SUBTITLE: Determination of Radium Removal Efficiencies in Water Treatment Processes	5. REPORT DATE: December 1976
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): W.L. Brinck, R.J. Schliekelman, D.L. Bennett, C.R. Bell, I.M. Markwood	8. PERFORMING ORGANIZATION REPORT NO.: ORP/TAD-76-5
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C. 20460	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS: Same as 9	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE: EPA-ORP

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Numerous well-water supplies for public water systems contain naturally occuring radium-226. Methods for removing radium from drinking water are needed so that drinking water treatment plants may meet the limit set in the EPA drinking water regulations for radium in drinking water.

Studies were performed by State agencies at 14 cities in Iowa and Illinois to determine the radium removal efficiency of four water treatment processes. Populations served by the water treatment plants ranged from 235 to 25,000. The radium-226 concentration in the raw water was greater than 5 pCi/liter at 13 of the supplies and ranged from 3 to 49 pCi/liter.

Radium removal efficiencies at plants utilizing reverse osmosis and sodium ion-exchange processes were generally about 92%. A much wider range of removal efficiencies, 75% to 95%, was found at plants utilizing the lime-soda ash softening process with the removal varying with process pH. Plants utilizing iron removal processes only were found to have radium removals ranging from 11% to 53%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water, Treatment, Removal Radioactivity, Radium	Potable Water Natural Radioactivity Water Treatment Chemical Removal	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*: Unclassified	21. NO. OF PAGES: 27
	20. SECURITY CLASS *(This page)*: Unclassified	22. PRICE: PCA03/MF A01

EPA Form 2220-1 (9-73)

TECHNICAL NOTE
ORP/TAD-76-5

PB 295321

DETERMINATION OF RADIUM REMOVAL EFFICIENCIES IN WATER TREATMENT PROCESSES

THE UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF RADIATION PROGRAMS

DECEMBER, 1976

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Technical Note
ORP/TAD-76-5

Determination of Radium Removal Efficiencies in Water Treatment Processes

by

William L. Brinck, P.E.
U.S. Environmental Protection Agency
Kansas City, Missouri 64108

R.J. Schliekelman, P.E.
Iowa Department of Environmental Qua ity
Des Moines, Iowa 50316

Dorothy L. Bennett

Charles R. Bell

Ira M. Markwood

Illinoi: Environmental Protection Agency
Sp ringfield, Illinois 62706

December, 1976

OFFICE OF RADIATION PROGRAMS
U.S. Environmental Protection Agency
Washington, D.C. 20460

EPA REVIEW NOTICE

This report has been reviewed by the Office of Radiation Programs, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report was prepared in order to summarize two extensive reports which examined the natural radioactivity source terms associated with radium in water supplies and the radium removal efficiencies of water treatment processes. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

David S. Smith
Director
Technology Assessment Division (AW-459)
Office of Radiation Programs

ABSTRACT

Numerous well-water supplies for public water systems contain naturally occuring radium-226. Methods for removing radium from drinking water must be identified so that drinking water treatment plants may meet the limit set in the EPA drinking water regulations for radium in drinking water, 5 pCi/liter.

Studies were performed by State agencies at 14 cities in Iowa and Illinois to determine the radium removal efficiency of four water treatment processes. Populations served by the water treatment plants ranged from 235 to 25,000. The radium-226 concentration in the raw water was greater than 5 pCi/liter at 13 of the supplies and ranged from 3 to 49 pCi/liter.

Radium removal efficiencies at plants utilizing reverse osmosis and sodium ion-exchange processes were generally about 92%. A much wider range of removal efficiencies, 75% to 95%, was found at plants utilizing the lime-soda ash softening process. Plants utilizing iron removal processes only were found to have radium removals ranging from 11% to 53%.

Pilot plant studies at the USEPA Cincinnati laboratory indicated that radium removal in the lime softening process is related to the pH used in the process. Higher radium removal efficiency accompanies higher pH values.

It is concluded that water treatment processes are available for removing radium from drinking water to meet the 5 pCi/liter limit.

TABLE OF CONTENTS

EPA Review Notice ii
Preface iii
Abstract. iv
Table of Contents v
List of Figures vi
List of Tables. vi
Conclusion. 1
Introduction. 2
Description of Study. 3
Results 5
    Reverse Osmosis 5
    Iron and Manganese Removal. 6
    Sodium Cation Exchange. 6
    Lime-Soda Ash Softening 9
    Pilot Plant 12
Summary of Results. 17
References. 18

LIST OF FIGURES

Figure No.		Page No.
1	Radium Removal vs. Softening pH	14

LIST OF TABLES

Table No.		Page No.
1	Cities Included in Radium Removal Studies	4
2	Ra-226 and Hardness Removals at Greenfield, Iowa Reverse Osmosis Plant	5
3	Ra-226 and Iron Removals at Water Treatment Plants Using Iron and Manganese Removal Processes.	7
4	Ra-226, Iron and Manganese Removals by Iron and Manganese Removal Processes	8
5	Ra-226 and Hardness Removals at Water Treatment Plants Using Ion Exchange Processes.	10
6	Ra-226 and Hardness Removals at Water Treatment Plants Using Lime-Soda Ash Softening	13
7	Ra-226 Removal in EPA Lime-Softening Pilot Plant Using Elgin, Illinois Water	16
8	Ra-226 Removal Efficiencies in Water Treatment Processes. . .	17

CONCLUSION

A study to determine the efficiency of radium removal by conventional water treatment processes indicates that reverse osmosis, ion-exchange and lime-soda ash softening are effective in removing the major portion of the radium from the water. High radium water was associated primarily with deep sandstone formations. The raw water radium concentrations ranged from 3 to 49 pCi/l at the water treatment plants studied.

Overall removal of radium at a reverse osmosis plant was 96% as compared with a concurrent hardness removal of 95% with a product water recovery of 69%.

Radium-226 removals in the sodium cation exchange process were generally above 90%, with the exception of Herscher, Illinois, where an 81% removal was noted. At the latter plant, about 53% of the radium-226 was removed in the aeration, settling and filtering pre-processing, before the ion exchange step. The data indicate that radium removal continues for a time after the hardness removal capacity is exhausted; thus a simple analysis for hardness may be used as an indicator when operating the plant for radium removal. In all of the ion-exchange softener installations 6 to 25 percent unsoftened water was bypassed around the softener and blended with the finished water being pumped to the distribution system to provide sufficient calcium carbonate for deposition of a protective coating on the water mains.

Overall removal of radium-226 by softening and filtering at lime-soda ash softening plants can reach 95%, dependent primarily on the pH of the process. Considerable variations in radium removals were noted depending on chemical dosage, pH range, magnesium removal, non-carbonate hardness removal and filtration efficiency. Most of the removal efficiencies were found to fall within the range of 75% to 96%.

Radium-226 extraction through iron removal units varied from 11% to 53% using aeration, detention and filtration. The manner of radium removal is possibly adsorption or catalytic action by the oxidation products (Fe(III) and Mn(IV)) deposited on the filter media.

Relatively high concentrations of radium in waste waters and sludges must be considered in determining the final disposal of these wastes. Currently, such wastes are generally discharged to watercourses. An exception is the discharge of lime sludge to evaporation lagoons in most instances. Additional research is needed to determine the most effective methods of waste disposal.

INTRODUCTION

Naturally occuring radium-226 is found in numerous well-waters. The U.S. Environmental Protection Agency (EPA) published interim regulations on July 9, 1976, which limit the concentration of radionuclides in public water systems (EN 76). Methods for removing radium had to be identified so that drinking water treatment plants may be designed to meet the limit for combined radium-226 and radium-228 of 5 pCi/liter.

Studies were performed by two State agencies, under EPA contracts, at 14 cities in Iowa and Illinois to determine the radium removal efficiency of four water treatment processes; reverse osmosis, aeration and iron removal, sodium cation exchange, and lime-soda ash softening (SC76 and BE76). This work was supplemented by a study at the water treatment pilot plant located in the EPA's Cincinnati laboratory.

DESCRIPTION OF STUDY

Water supplies were selected for the study on the basis of (1) high raw water gross alpha or radium-226 content (13 of the 14 supplies had radium-226 concentrations greater than 5 pCi/l in raw water), (2) a variety of water treatment processes, (3) availability for continous operation during the study and (4) a range of municipal populations served. A list of the cities included in the study and some pertinent characteristics is shown in Table 1.

Samples were collected from raw water supply wells and from points where treated water enters the distribution system. In addition, treatment systems in Iowa and at Herscher, Illinois, were sampled at various points throughout the treatment processes to determine changes and removals of radium and other pertinent chemical parameters. Flows and other data were obtained to determine whether plants were meeting design rates and to provide data for determining a material balance of radium-226 removals.

A significant difference between the two States' efforts was that, in Iowa, each treatment system was sampled over the course of an operating cycle, with numerous samples taken throughout the process whereas, in Illinois, each system was sampled on each of three separate occasions at approximately one-week intervals. Thus the results from Iowa give a detailed picture of system operation, while the results from Illinois give an indication of the variation of operating characteristics over a period of three weeks. Samples of well water were generally collected near the beginning of a pumping period and following longer pumping times to determine any time related variability in radium, hardness and other chemical parameters during pumping.

Radium-226 analyses were performed in Iowa at the Iowa State Hygienic Laboratory using coprecipitation with mixed barium and lead sulfates in accordance with Standard Method ASTM D 2460-70. Illinois radium-226 analyses were performed by the Argonne National Laboratory using the radon emanation method. Some samples were collected in duplicate for intra-laboratory collaborative testing to check the accuracy of the radium-226 analysis.

The pilot plant in Cincinnati was used to investigate the removal of radium-226 under ideal conditions of lime softening at two different pH levels, 9.5 and 10.6. The raw water was brought to Cincinnati by truck from the Slade Avenue plant in Elgin, Illinois. Samples were collected of raw water, treated water, and at two points in the treatment process, and were analyzed using the radon emanation procedure by EPA in Cincinnati.

TABLE 1

Cities Included in Radium Removal Studies

City	Population Served	Plant Capacity (m^3/day)	Raw Water Ra-226 (pCi/l)	Remarks
Reverse Osmosis				
Greenfield, Iowa	2212	570	14	
Iron Removal				
Adair, Iowa	750	380	13	Aeration & continuously regenerated greensand filters
Stuart, Iowa	1354	530	16	Aeration & pressure iron removal filtration
Ion Exchange				
Dwight Correctional Center, Illinois	235	110	3.3	
Eldon, Iowa	1319	360	49	
Estherville, Iowa	8108	3300	5.7	
Grinnell, Iowa	8402	3790	6.7	
Herscher, Illinois	1000	380	14.3	
Holstein, Iowa	1445	590	13	
Lynwood, Illinois	4000	600	14.7	
Lime-Soda Ash Softening				
Elgin, Illinois	25,000	18,000	5.6	
Peru, Illinois	12,400	6830	6.0	
Webster City, Iowa	8488	5000	7.8	
West Des Moines, Iowa	16,441	9730	9.3	

RESULTS

Reverse Osmosis

In the reverse osmosis demineralizing process the high hardness water is pressurized and piped into a reverse osmosis unit where relatively pure water diffuses through the semipermeable membrane and becomes the product water, leaving a concentrated reject water. The much greater rejection of divalent ions, such as Ca, Mg, Ra and SO_4, than the monovalent ions, Na and Cl, is characteristic of essentially all reverse osmosis membranes.

The usual water supply for Greenfield, Iowa, is an impoundment of surface water. A reserve source of water from a deep well is used during periods of drought. The brackish well water, with a total solids content of more than 2200 mg/l, is treated in a reverse osmosis unit installed in 1971. A description of the plant and discussion of operating results was published in 1972 (MO 72). Raw, product, and reject water samples were collected and analyzed for radium-226 and other chemical constituents. The results are shown in Table 2.

TABLE 2

Ra-226 and Hardness Removals at Greenfield, Iowa
Reverse Osmosis Water Treatment Plant

Sampling Point	Ra-226		Hardness	
	pCi/l	Percent Removal	mg/l as $CaCO_3$	Percent Removal
Well Supply	14		610	
RO Plant Effluent	0.6	96	29	95

The average radium-226 concentration in the reject water was 43 pCi/l, where 31% of the influent water was rejected and 69% was converted to low hardness product water.

Iron and Manganese Removal

The presence of iron and manganese in drinking water is objectionable primarily because of taste and the precipitation of these metals turns the water a turbid yellow-brown color. The treatment processes employed in the removal or control of iron and manganese include:

1. Precipitation and filtration
    a. Aeration, detention (or sedimentation) and filtration
    b. Oxidation by potassium permanganate, chlorine or chlorine dioxide
2. Ion exchange
    a. Continuously regenerated permanganate greensand filter

Iron and manganese removal is utilized in some form of pretreatment at five ion-exchange softening plants and as the only removal process at two other plants selected for study. The results are shown on Table 3.

A tabulation of radium removal, iron removal, manganese removal and pH (Table 4) suggests that radium-226 is being removed on the manganese, just as Mn-impregnated fibers have been reported to remove radium (MO 75). There are radium-226 removals of 46-56% when there is a significant manganese removal. Fair (FA 68) notes that "Hydrous oxides of Fe(III) and Mn(IV) have high sorption capacities for bivalent metal ions." Also, "Sorption capacities for Mn^{++} at pH 8 are on the order of 1.0 and 0.3 mole of Mn(II) sorbed per mole of MnO_2 and $Fe(OH)_3$, respectively." Although this may explain the removal of radium at these plants, further studies are required to confirm this theory.

It was noted at several supplies that there was significant reduction in radium-226 content after aeration and detention alone, before the water was filtered. Further studies will be required to fully understand this phenomenon.

Sodium Cation Exchange

Water softening by the sodium cation exchange (zeolite) process depends upon the ability of certain substances to exchange cations with other cations dissolved in water. When hard water is passed through a sodium cation exchanger, the calcium and magnesium in the hard water replaces the sodium on the exchange medium. Because the reaction is reversible, after all of the readily replaceable sodium has been exchanged, the cation exchange medium can be regenerated with a solution of sodium chloride. In the regeneration process, the calcium and magnesium on the exhausted cation exchanger are replaced with a fresh supply of sodium from the regenerating brine solution. Then, after washing to free it from the calcium and magnesium cations and excess salt, the regenerated exchanger is ready to soften a new supply of

TABLE 3

Ra-226 and Iron Removals at Water Treatment Plants Using Iron and Manganese Removal Processes

City	Filter Type	Sampling Point	Ra-226 pCi/l	Ra-226 Percent Removal	Iron mg/l	Iron Percent Removal
Iron and Manganese Removal Only						
Adair	Greensand	Well	13		1.1	
		Filter Eff.	8	38	0.02	98
Stuart	Anthrafilt	Well	16		0.94	
		Filter Eff.	12	25	0.03	97
Iron Exchange Pretreatment						
Eldon	Anthrafilt	Well	49		2.0	
		Filter Eff.	43	12	0.3	85
Estherville	Anthrafilt	Well	5.7		2.0	
		Filter Eff.	5.1	11	0.67	66
Grinnell	None	Well	6.7		0.71	
		Detention Eff.	5.7	15	0.41	42
Herscher	Anthrafilt	Well	14.4		0.1	
		Filter Eff.	6.7	53	0.0	
Holstein	Anthrafilt	Well	13		1.8	
		Filter Eff.	7.2	45	0.05	97

TABLE 4

Ra-226, Iron and Manganese Removals by Iron and Manganese Removal Processes

City	Ra-226 (pCi/1)			Iron (mg/1)			Manganese (mg/1)		
	Raw	Treated	%Removal	Raw	Treated	%Removal	Raw	Treated	%Removal
Adair	6.9	6.7	3	0.5	0.01	80	0.01	0.01	-
	pH 6.7-6.9								
Eldon	49	43	12	2.0	0.3	85	0.01	0.01	-
	pH 7.8								
Estherville	5.7	5.1	11	2.0	0.67	66	0.24	0.27	-
	pH 7.7								
Grinnell	6.7	5.7	15	0.7	0.41	42	0.01	0.01	-
	pH 7.6								
Herscher	14.9	6.6	56	0.2	0	-	0.47	0.02	96
	14.5	6.4	56	0.4	0	-	0.41	0.01	98
	14.9	6.9	54	0.1	0	-	0.48	0.01	98
	14.3	6.9	52	0.1	0	-	0.39	0	100
	14.0	6.9	51	0.1	0	-	0.45	0	100
	13.9	6.8	51	0.1	0	-	0.63	0	100
	13.9	7.3	47	0.2	0.1	-	0.44	0.13	70
	14.1	6.3	55	0.1	0	-	0.53	0.02	96
	14.3	6.5	55	0.1	0	-	0.50	0	100
	pH 7.6-7.9								
Holstein	13	7	46	1.8	0.09	95	0.15	0.01	93
	pH 7.4-7.6								
Stuart	16	12	25	0.94	0.03	97	0.01	0.01	-
	pH 7.6-7.9								

hard water. The ion-exchange media studied included both naturally occurring greensand and synthetic polystyrene resins (zeolite).

Ion exchange softening removes nearly 100% of the hardness from the treated water. Consequently, unsoftened water is blended with the ion exchange softener effluent to provide sufficient calcium carbonate for deposition of a protective coating on the water mains and to reduce treatment costs. Thus the water entering the distribution system usually has a greater radium concentration than that leaving the softener. The radium concentration in raw water could be the controlling factor in the amount of blending that would be permitted in order to meet the radium limit in drinking water.

The results of the measurements at ion exchange process water treatment plants are shown in Table 5.

The data shown from the plants in Illinois are the averages of nine separate data points. Ranges in the percent reduction of radium-226 through softeners at the three cities are:

Dwight	70.7 - 98.3
Herscher	68.4 - 93.9
Lynwood	94.7 - 98.2

It was determined that the removals vary somewhat over a softener cycle, between regenerations. Radium-226 removal usually continues for a short period after hardness breakthrough occurs. However, if the cycle continues for a longer period after hardness breakthrough, radium-226 removal drops rapidly.

Samples of softener brine and rinse effluent during regeneration were taken at various times during the regeneration cycle. Regeneration normally requires one to two hours. It was found that the major portion of the radium-226 leaves the ion-exchange media over a rather short period - 10 to 30 minutes. Maximum radium-226 concentrations in the softener brine and rinse effluents ranged from 320 to 3500 pCi/l.

Lime- oda Ash Softening

This process of softening depends on the use of lime and soda ash to change the soluble calcium and magnesium compounds into nearly insoluble compounds which are flocculated, settled and filtered. Conditions for carrying out the precipitation of calcium and magnesium vary because different pH levels are needed for each, about pH 9.5 for maximum precipitation of calcium carbonate and pH 10.5 for maximum precipitation of magnesium hydroxide. Thus, if the magnesium concentration is low, treatment to a pH of 9.5 will be sufficient. If the magnesium concentration is high, excess lime, to produce a pH of 10.5, can be used. A more economical treatment is to raise the pH to 10.5 to precipitate the magnesium in a primary basin, then recarbonate with carbon dioxide to pH 9.5 to precipitate excess calcium in a secondary basin.

TABLE 5

Ra-226 and Hardness Removals at Water Treatment Plants Using Ion Exchange Processes

City	Softener Type	Sampling Point	Ra-226 pCi/l	Ra-226 Percent Removal	Hardness mg/l	Hardness Percent Removal
Dwight Correctional Center	Greensand	Well	3.25		280	
		Softener Eff.	0.36	89	43	85
		Distribution System	0.65		67	
Eldon	Zeolite	Softener Influent	43		360	
		Softener Eff.	1.9	96	10	97
		Distribution System	8.6		136	
Estherville	Zeolite	Softener Influent	5.1		915	
		Softener Eff.	0.3	94	46	95
		Distribution System	0.4		76	
Grinnell	Zeolite	Softener Influent	5.7		387	
		Softener Eff.	0.2	97	11	97
		Distribution System	1.4		120	

TABLE 5 (cont.)

Ra-226 and Hardness Removals at Water Treatment Plants Using Ion Exchange Processes

City	Softener Type	Sampling Point	Ra-226 pCi/l	Ra-226 Percent Removal	Hardness mg/l	Hardness Percent Removal
Hersher	Zeolite	Softener Influent	6.7		404	
		Softener Eff.	1.3	81	83	79
		Distribution System	2.4		141	
Holstein	Zeolite	Softener Influent	7.2		885	
		Softener Eff.	0.5	93	18	98
		Distribution System	0.8		346	
Lynwood	Zeolite	Well	14.7		848	
		Softener Eff.	0.4	97	-	
		Distribution System	1.8		78	

Normally, soda ash is added as needed to precipitate non-carbonate hardness, but due to a soda ash shortage, the West Des Moines plant was using only a small quantity. The Webster City plant was using lime only during the August, 1974 measurements, but was using soda ash during the February, 1975 restudy.

Results of measurements obtained at water treatment plants using lime-soda ash softening are shown in Table 6. That the pH of the softening process is a parameter that controls radium removal, at least for water containing both calcium and magnesium, is demonstrated in Table 6 and in Figure 1. The least squares fit for a straight line through the data points of Figure 1 indicates that the radium removal percentages increased as the pH of the process increased.

The data shown from the plants in Illinois are the averages of three separate data points, taken at approximate one-week intervals. Ranges in the percent reduction of radium-226 at the two cities are:

Elgin	86.0 - 89.9
Peru	70.6 - 92.4

Samples of lime sludge and filter backwash water were also collected. The results were:

	Lime Sludge Ra-226	Filter Backwash Ra-226
Elgin	6.1 pCi/g	18.3 pCi/l
Peru	9.0 pCi/g	36.9 pCi/l
Webster City	980 pCi/l	50 pCi/l
West Des Moines	2300 pCi/l	6.3 pCi/l

Pilot Plant (SO 75)*

The Environmental Protection Agency Municipal Environmental Research Laboratory, Cincinnati, Ohio, operates a conventional coagulation water treatment pilot plant. The pilot plant, designed for flexibility in operation, is capable of treating in parallel two 7.6 l/min. streams of water.

The two treatment systems each consist of two rapid mix tanks (in series), flocculation basin, sedimentation basin, and one or more filters (in parallel). The theoretical detention times for the mix tanks, and flocculation and sedimentation basins are 1 minute, 60 minutes, and 4.5 hours respectively.

---

*We thank Mr. Thomas J. Sorg, Research Engineer, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, for providing access to, and the operation of the pilot plant.

TABLE 6

Ra-226 and Hardness Removals at Water Treatment Plants Using Lime-Soda Ash Softening

City	Sampling Point	Ra-226 pCi/l	Ra-226 Percent Removal	Hardness mg/l	Hardness Percent Removal	pH of Process
Elgin	Well	5.6		237		
	Filter Eff.	0.8	86	102	57	
Peru	Well	5.8		326		
	Filter Eff.	1.1	81	94	71	
Webster City	Well	6.1		507		
(Aug. 1974)	Clarifier #1 Eff.	1.9		333		10.0
	Clarifier #2 Eff.	2.6		282		10.1
	Filter Eff.	0.9	85	262	48	9.3
Webster City	Well	7.8		482		
(Feb. 1975)	Clarifier Eff.	0.6		150		11.0
	Filter Eff.	0.3	96	106	78	9.9
West Des Moines	Well	9.3		376		
	Contact Unit Eff.	2.6		215		10.1-10.4
	Filter Eff.	2.4	75	190	50	9.4-9.5

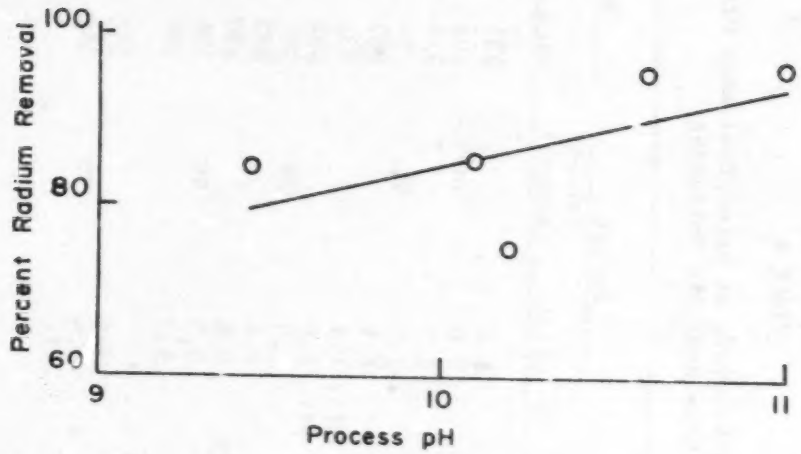

Figure I Radium Removal vs Softening pH

The water to be treated is pumped to the first rapid mix tank. Normally, the pH control chemical is added in the first mixing tank and coagulant introduced in the second tank. From the mixing tanks, the water flows by gravity through the flocculation and settling basins to the filters, which consist of 10.8 cm diameter clear plastic cylinders providing 93 cm^2 of media surface area. A pump on the effluent side of each filter controls the flow rate through the filter with the excess water wasted through an overflow located several feet above the filter media. For the radium removal studies, two parallel filters were used. One was a dual-media filter containing 50.8 cm of No. 1-1/2 Anthrafilt over 30.5 cm of 0.4 mm effective size Muscatine sand. The other filter consisted of 76.2 cm of granular activated carbon, Filtersorb 200. The filtration rate was controlled at 163 $l/min/m^2$.

The plant has instrumentation to record pH of the raw, flocculated, settled, and filtered water; turbidity and temperature of the raw, settled, and filtered water; head loss in the filters; and volumes of raw and filtered water pumped.

Two test runs in August, 1975, were made to determine the removal of radium-226 from Elgin, Illinois raw water by lime softening. The tests lasted about 100 hours each and were run at pH 9.5 and 10.5. The raw water was trucked from the Elgin Slade Avenue treatment plant to Cincinnati, Ohio.

For the first test run, lime, at 220 mg/l, was fed into the second rapid mix tank to increase the pH to 9.5. Commercial grade lime was used and fed as a 4 percent slurry. The water was then flocculated, settled and filtered.

Duplicate one liter grab samples of the raw, settled and filtered water were collected three times during the test period. The settled and filtered samples were collected about 7 hours after the raw sample, the approximate time required for the water to flow through the flocculation and settling basins. All samples were preserved with 1.5 ml of nitric acid.

The pilot plant was operated in a slightly different manner during the second test run. For this test, 270 mg/l of lime was added to increase the pH to 10.5. After settling, the treated water was pumped through the other treatment system where the water was recarbonated to lower the pH to 8.6, settled for a second time, and then filtered. Grab samples were also collected of the raw, settled, and filtered water. Water samples from the first settling basin were collected about 7 hours after the raw sample. Water samples from the second settling basin and filters were collected about 14 hours after the raw sample.

Results of the two tests indicated that pH affects the removal of radium-226 (Table 7). Lime softening at pH 9.5 resulted in removals of 79 percent for settled water and 84 percent for filtered water. Excess lime softening to a pH 10.5, achieved 92-93 percent removals in the settled water and 93-95 percent in the filtered water. Little or no difference in removals were noted between the two types of filters indicating that the carbon filter did not achieve any additional removal by adsorption.

TABLE 7

Ra-226 Removal in EPA Lime-Softening Pilot Plant
Using Elgin, Illinois Water

Softened to pH 9.4 - 9.5

	August 6, 1975		August 7, 1975		August 8, 1975		Average	
	Conc. pCi/l	D.F.,%*	Conc. pCi/l	D.F.,%	Conc. pCi/l	D.F.,%	Conc. pCi/l	D.F.,%
Raw	4.19	-	3.95	-	4.87	-	4.34±.48	-
Settled	1.03	75.4	0.94	76.1	0.69	85.9	0.89±.18	79.1±5.9
Dual-Media Filter	0.79	81.1	0.65	83.6	0.61	87.4	0.68±.09	84.0±3.2
Activated Carbon Filter	0.75	82.1	0.62	84.4	0.65	86.6	0.67±.07	84.3±2.3

Softened to pH 10.6, Recarbonation to pH 8.7

	August 20, 1975		August 21, 1975		Average	
	Conc. pCi/l	D.F.,%	Conc. pCi/l	D.F.,%	Conc. pCi/l	D.F.,%
Raw	4.78	-	4.86	-	4.82±.19	-
First Settling Basin	0.37	92.4	0.39	92.0	0.38±.02	92.2±0.3
Recarbonation Settling Basin	0.33	93.1	0.36	92.5	0.35±.02	92.8±0.4
Dual-Media Filter	0.30	93.7	0.30	93.8	0.30±.00	93.8±0.1
Activated Carbon Filter	0.18	96.2	0.28	94.3	0.23±.07	95.2±1.3

*D.F. - Decontamination Factor (The Removal Efficiency)

SUMMARY OF RESULTS

The radium removal efficiencies of four water treatment processes are shown in Table 8.

TABLE 8

Ra-226 Removal Efficiencies in Water Treatment Processes

Process	City	Percent Removal
Reverse Osmosis	Greenfield, Iowa	96
Iron Removal	Adair, Iowa	38
	Eldon, Iowa	12
	Estherville, Iowa	11
	Grinnell, Iowa	15
	Herscher, Illinois	53
	Holstein, Iowa	45
	Stuart, Iowa	25
Ion Exchange	Dwight Correctional Center, Illinois	89
	Eldon, Iowa	96
	Estherville, Iowa	94
	Grinnell, Iowa	97
	Herscher, Illinois	81
	Holstein, Iowa	93
	Lynwood, Illinois	97
Lime-Soda Ash Softening	Elgin, Illinois	88
	Peru, Illinois	81
	Webster City, Iowa, pH 11.0	96
	West Des Moines, Iowa, pH 10.1	75
	Cincinnati Pilot Plant, pH 9.5	84
	Cincinnati Pilot Plant, pH 10.6	95

REFERENCES

EN 76 Environmental Protection Agency, 1976, "40 CFR 141 Interim Primary Drinking Water Regulations, Radionuclides," Federal Register 41, 28402.

BE 76 Bennett, D.L., Bell, C.R. and Markwood, I.M., 1976, USEPA Rept. ORP/TAD-76-2, "Determination of Radium Removal Efficiencies in Illinois Water Supply Treatment Processes."

FA 68 Fair, G.M., Geyer, J.C., Okun, D.A., 1968, Water and Wastewater Engineering, Vol. 2.

MO 72 Moore, D.H., 1972, "Greenfield, Iowa, Reverse Osmosis Desalting Plant, "Journal American Water Works Association, 64, 781.

MO 75 Moore, W.S., Cook, L.M., 1975 "Radium Removal from Drinking Water," Nature, 235.

SC 76 Schliekelman, R. J., 1976, USEPA Rept. ORP/TAD-76-1, "Determination of Radium Removal Efficiencies in Iowa Water Supply Treatment Processes."

SO 75 Sorg, T. J., 1975, Personal Communication, USEPA, Municipal Environmental Research Laboratory, Cincinnati, Ohio.